CHAPTER 20

GEOLOGICAL ASPECTS OF SITE SELECTION FOR LOW AND INTERMEDIATE LEVEL RADWASTE REPOSITORY IN SLOVENIA

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Abstract. According to the guidelines for a low and intermediate level radwaste repository site selection in Slovenia, the siting process has been divided into four steps. The first three steps of the surface site selection were completed in 1993. A set of the most exclusionary geological criteria to be applied in selecting the surface site is described. Some reasons for the failure of this process are also described. Since the fourth step was stopped due to strong public opposition, an alternative of underground disposal is now being considered. In 1994, the Agency for Radwaste Management started the preparation of basic guidelines for underground repository site selection. Joint recommendations, that consider both surface and underground site selection parameters, are now being developed in the Slovenian Nuclear Safety Administration.

20.1 INTRODUCTION

The guidelines for the selection of a low and intermediate level radwaste (LILW) disposal site were setup in 1991. The guidelines that were announced included rules according to which, under the given urban and social conditions, the most suitable site for the shallow ground disposal of LILWin Slovenia would be selected. Both the existing world-wide experience and the national regulatory conditions in Slovenia were considered in creating these guidelines.

In selecting disposal sites, it was necessary to have a detailed knowledge of the process of migration of contaminants into the biosphere. Slovenia has a very sophisticated geological and tectonic setting dominated by various combinations of geological structural elements such as: faults of different type and age, overthrusts, folds, naps and lateral transformations of different lithologic units. In most cases, it was very difficult to determine the migration of radionuclides in underground water. Thick layers of impermeable rocks are the only reliable natural barrier in such geological and hydrogeological conditions.

However, the requirements given by the guidelines are that a shallow disposal site is to have rocks of low permeability in the basement, and a distance to the underground water table that is as large as possible. Sites with these geological conditions, such as saturated clay marls, were the only ones selected as being acceptable. These rocks, regardless of fracturing in neighboring layers, provide a sufficient natural barrier to prevent migration of radionuclides.

20.2 SITE SELECTION PROCESS FOR LILW

The procedure used in selecting disposal sites was divided into three steps containing 43 criteria. In a final fourth step, the technical confirmation was based on a detailed field examination of the geology, hydrogeology, and seismology of the site. Each step was terminated by a presentation to the public of the results.

In the first step, unsuitable areas were excluded by taking into consideration certain exclusion criteria, such as: national parks, urban zones, ground water resources, presence and location of active faults, geothermal areas, flood areas, presence of ores, minerals, oil, gas, hydraulic conductivity, soil composition, thickness and extent of geologic units.

In the second step, the remaining acceptable areas were evaluated according to land use, water resources, seismic and geological criteria, so they could be further reduced to so called potential sites.

In the third step, several of the most suitable of the potential sites were chosen by comparing their locations on the basis of the following criteria: population, economic feasibility, transport, ecological value, and public acceptance.

In the final fourth step, a comprehensive analysis of the most suitable sites from the third step was carried out by applying the criteria of the previous steps and additional criteria concerning the corrosion of waste containers (biological processes, chemical properties of the soil and groundwater), and then a detailed field investigation was carried out to confirm the suitability of the sites. The results of the fourth step produced one or two of the most suitable sites that were considered to be technically confirmed. A schematic diagram of this process is shown in Figure 20.1

20.2.1 Step One of Site Selection

In carrying out Step One, a series of overlaying maps were used which contained areas that are defined by seven exclusionary criteria as described in Table 20.1. This process eliminated the unsuitable areas of the Republic of Slovenia from further consideration.

After considering the exclusionary criteria of the first step, the acceptable areas for an LILW repository site in

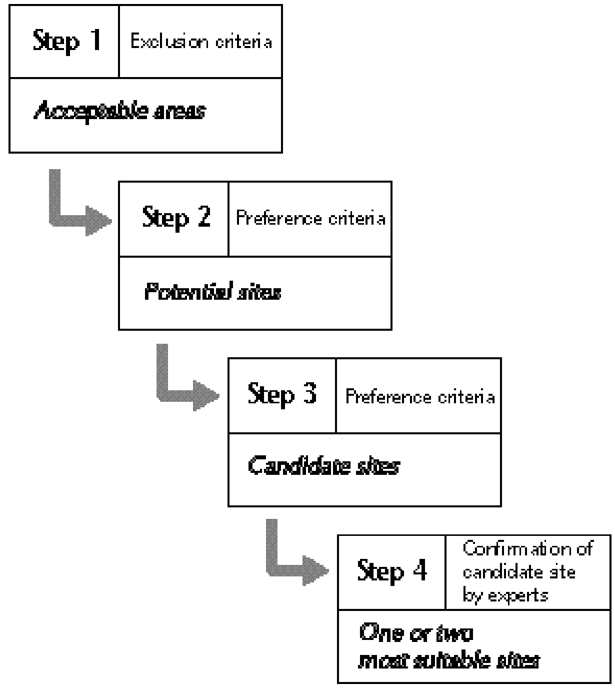

Figure 20.1. Schematic diagram of the site selection process for LILW in Republic of Slovenia.

Table 20.1. Exclusionary criteria of Step One.

Exclusion Criteria	Explanation
National Parks	The areas defined as national parks are excluded.
Urban Zones and Settlements	Excluded are all areas defined as settlements with more than 5000 inhabitants.
Drinking Water Resources–Aquifers	Excluded are all areas defined as drinking water resources.
Known Active Geological Faults, Geothermal Areas and Seismicity	Excluded are all areas located on a known active fault at a distance up to 3 km and the areas where the expected earthquake acceleration exceeds 0.3 g.
Flood Areas	Excluded are areas which are located in an area of 500 year floods.
Presence of Ores, Minerals, Oil and Gas	Excluded are areas with proven resources of ores, mineral, oil and gas.
Geological and Lithological Soil Composition	Excluded are the areas where surface homogeneity of layers is smaller than 300x300 m and the quotient between the thickness and hydraulic conductivity of layers is smaller than 5×10^9 s. Excluded are lithological layers having a hydraulic conductivity greater than 1×10^{-8} ms^{-1} and a thickness of layers smaller than 20 m.

Slovenia were identified. The potentially acceptable areas were those that had not been excluded according to any criterion of Step One. All of these areas were considered to be equivalent, i.e., the acceptable areas had not been assessed and evaluated. Figure 20.2 shows the locations of the acceptable areas after the application of the first step.

20.2.2 Step Two of Site Selection

In carrying out Step Two, the preference criteria were divided into four groups: geological, seismic, land use, and potential water management. These criteria were then applied to the acceptable areas selected in the first step.

The following geological preference criteria were applied:

- Presence of groundwater;
- Site seismicity;
- Presence and vicinity of active faults;
- Exploitation of ores/minerals, oil and gas;
- Areal extent of host rock;
- Thickness of rock mass;
- Soil instability;
- Erodibility;
- Rock composition and hydraulic conductivity;
- Angle of slopes; and
- Radionuclide paths to the biosphere.

The result was the selection of 36 potential sites occupying a total area of approximately nine km^2.

The examination of the potential locations was performed at the end of the theoretical studies to verify the procedure, and to determine discrepencies in the results obtained. This examination resulted in an expert conclusion that: (a) five locations are not suitable for the construction of a repository, and (b) another five locations are only suitable for a tunnel type repository and not for a surface type as previously envisioned. One potential site, suitable for both types of repository, was also identified and considered in further analysis.

The results of the second step of surface repository site selection were reviewed by a group of experts that confirmed the accordance of the procedure with the guidelines.

20.2.3 Step Three of Site Selection.

In the the third step, five candidate sites were selected among 36 potential sites from the second step. The

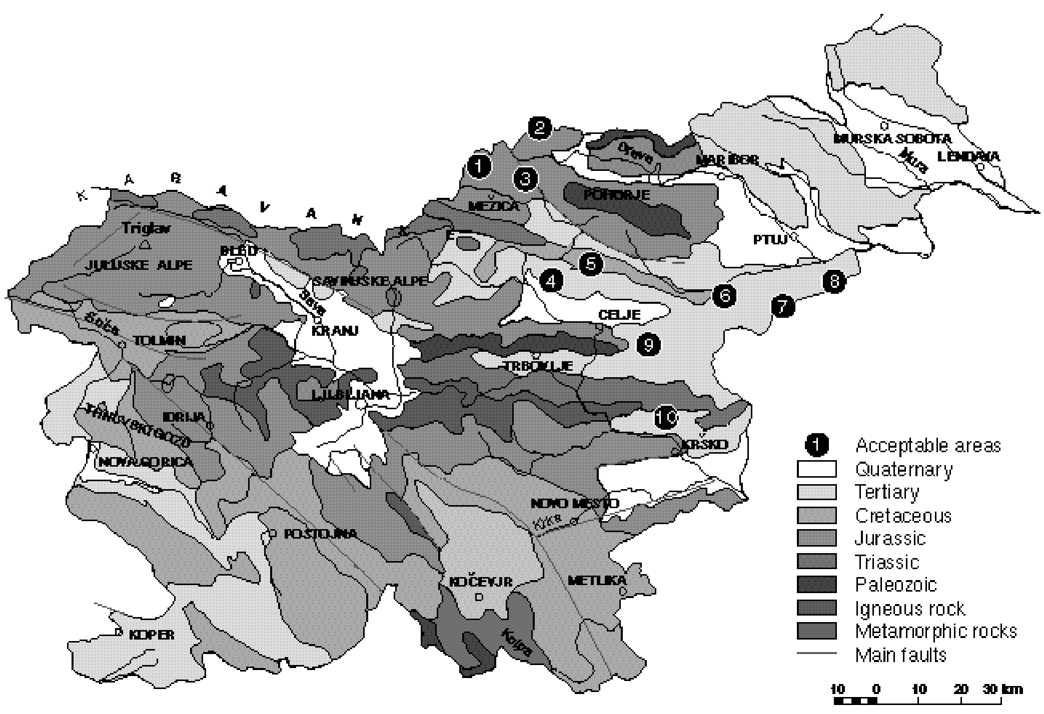

Figure 20.2. A generalized geological map of Slovenia with acceptable areas after the application of Step One.

method of assessment was based on the repeated use of the criteria from the first two steps. In addition, preference criteria concerned with economic and technical feasibility, transport, and social acceptability were considered as well.

One of the selected sites was found to be suitable for a surface repository, two, for a tunnel repository, and the remaining two sites were appropriate for either type of repository, surface or tunnel. The main geological characteristics of the sites are summarized in Table 20.2.

In accordance with the practice from previous steps in this procedure, the results were presented to the public. The presentation was not successful and has provoked strong disapproval within the local communities. Their representatives declared that waste disposal in the vicinity of their communities was not acceptable. It was evident that public acceptance of the candidate locations could not be achieved. Therefore, it was impossible to proceed to the fourth step in which the most suitable locations could be verified and approved by the experts. The project was stopped.

20.3 DID APPLICATION OF GEOLOGICAL CRITERIA INFLUENCE AN UNSUCCESSFUL SURFACE REPOSITORY SITE SELECTION?

It is clear the natural site characteristics play an important role in the selection process for a radioactive waste

Table 20.2. The main gelogical characteristics of the sites.

	Main Geological Characteristics	Site 1 Surface Repository	Site 2 Tunnel Repository	Site 3 Tunnel Repository	Site 4 Surface or Tunnel Repository	Site 5 Surface or Tunnel Repository
HOST ROCK	Rock Type	Sandy marl	Sandy marl	Sandy marl	Marl	Marl
	Permeability (m/s)	10^{-9}-10^{-11}	10^{-9}-10^{-11}	10^{-9}-10^{-11}	$10^{-11} < K < 10^{-9}$	$10^{-11} < K < 10^{-9}$
	Relative Porosity (%)	22	22	22	20-33	20-33
	Thickness of Layer (m)	300-400	300-400	300-400	50-400	50-400
	Areal extent of Rock Mass (ha)	11	332	104	19	28
	Angle of Slope (°)	10-20	5-20	5-20	10-15	10-20
	Erodibility (mm/300 yrs.)	4.2-5.4	3.2-7.5	6.4-8.6	5.4-6.4	4.2
	Point Load Index I_s (50) MN/m^2	0.87-1.94	0.87-1.94	0.87-1.94	0.09-0.31	0.09-0.31
	Unconfined Compressive Strength (MPa) $Q_u=22\ I_s$	17.17-42.71	17.17-42.71	17.17-42.71	1.99-6.73	1.99-6.73
	Natural Volume Weight (KN/m^3)	20.95	20.95	20.95	18.22-19.43	18.22-19.43
	Distance from Active Faults (km)	3-4	3-4	3-4	3-4.6	3-4.6
	Max. Expected Horizontal Acceleration in a Time Period of 1000 years (cm/s^2)	190	190	190	250	250
	Max. Expected Local Intensivity in a Time Period of 1000 years (MCS)	8	7-8	7-8	8	8

repository site, and that a site within an appropriate geological environment is, to a great extent, based on geological conditions.

But geological criteria, applied to the process of selecting a surface repository site in Slovenia, used only properties of the geological barrier and took no account of the other two barriers, i.e., conditioned waste and engineered barriers. In other words, the objective of finding a site for a surface repository was *to find a location with geological properties (natural geological barriers), where engineered barriers would not necessarily be used to achieve the safety standards.* This was certainly the most economic way for repository construction, but on the other hand, the site selection was exceptionally difficult.

The siting process applied highly quantitative exclusionary or preference geological criteria, i.e., geological criteria were stated with numerical values of the geological parameters, that made the whole siting process very inflexible. Some geological criteria, according to their "importance" (according to the size of the excluded areas in surface repository site selection) are presented and described in the following.

The criterion of "active faults" as a single tectonic exclusionary criterion has eliminated 97% of Slovenia for the purpose of siting a repository. To meet this criterion, areas located in the vicinity of a known active fault at a distance up to three km were unsuitable.

Considering the same criterion in the second step, i.e., presence and vicinity of active faults, acceptable areas from the first step ranged over the following distances:

- Unsuitable sites, where the site was to be located on, or near a fault, at a distance up to 3 km;
- Less suitable sites, where the distance from the fault is 3 to 8 km; and
- Suitable sites, where the distance is greater than 8 km.

It should be noted that up to the third step, the work included office work only, and no site investigations were performed to confirm activity of the faults.

Although Slovenia lies in a seismic territory, and tectonic causes of seismic activity, i.e. surface faults, are distributed all over Slovenia, there is a basic question (that could be discussed) whether the application of a uniform step-off distance is a matter of policy rather than being grounded on technical principles. Without detailed site investigations, it is difficult to select suitable locations, and the geological properties of specific sites must first be confirmed through field investigations.

According to the criterion for "Active faults", the WAMAP mission[5] recommended that at an early stage, it is important to decide on the definition for an active fault and the significance that rock structure could have on the integrity of a repository over its 300-year assessment period. It is necessary to have a single representative data base, or set of maps, supporting the interpretation and application of this criterion.

A similar situation occurred in the first step in connection with the "Lithology" criterion, where rocks with a hydraulic conductivity greater than 10^{-8} m/s, a thickness of layers less than 20 m, and a seismicity where earthquake accelerations greater than 0.3 g would be expected, were recognized as unsuitable. In further analysis, the Lithology of acceptable areas was compared considering the preference criteria "Areal extent of host rock" and "Thickness of rock mass", where the area suitability increased with extent (greater than 300 x 300 m, i.e., 9 ha) and layer thickness (more than 20 m). Again, this site analysis only involved office work. No field investigations, to confirm exclusive parameters for the rocks, was made.

In considering the preference criteria "Site seismicity", acceptable areas ranged between unsuitable (where the expected earthquake accelerations a_{max} exceeds 0.3 g for a period of 1,000 years), less suitable (a_{max} = 0.15 to 0.3 g) and suitable (a_{max} is less than 0.15 g). The maximum horizontal ground acceleration for the territory of Slovenia was evaluated with a probabilistic seismic hazard analysis.

The mission report[5] suggested that in general, an application of highly quantitative exclusion or site preference criteria, especially at an early stage of the selection process, was not recommended.

Quantitative criteria, as applied in the siting process and as described above, can only be used where quantitative data are available to justify their use, i.e., data confirmed by site investigations. Much of existing technical data is regional (non-site specific) and qualitative in nature as well. Some criteria, used in the first (exclusionary) step simply assume certain site specific data, which would only be available in the necessary detail after a careful site investigation. Such criteria should therefore be left to the appropriate later steps in repository siting[5].

It is very important to recognize the uncertainties in understanding the geology during the siting process, when data are based only on office studies. The actual site conditions may be significantly different from those envisaged, and as a result, the site selection process must remain flexible enough in order to accomodate unexpected features. More confidence can be placed in sites selected in a location where the geological structure is non- or less complex.

20.4 NEW APPROACHES

According to the fact that the necessity for the final disposal of low and intermediate level radioactive wastes is growing, the final location of the disposal site should be selected within the next five to ten years. The existing wastes are temporarily stored in interim storage facilities located at the Krsko nuclear power plant.

It is obvious that problems concerning final disposal of LILW should be solved in a satisfactory manner in the near future. Solutions for this problem are being searched for in the following directions:

1. In verification, new estimates and corrections of the three most exclusionary geological criteria (active faults, seismicity, and hydrogeological parameters), but the most important features have been revealed in the application to sites for final waste disposal.
2. In considering the newest techniques and technologies that have been developed in disposing of, and protecting, radwastes in the developed countries, and in reconsidering geological criteria in this new light.
3. In taking into consideration the possibility of underground waste disposal of LILW in geological structures, and in this way minimizing the risks arising from the seismicity and activity of fault zones.

In the analysis of the reasons for failure in the first campaign, it appeared that there was a bad coordination between experts in the different fields of science. For example, geologists considered “impervious” rock as the only suitable rock for a disposal site, regardless of the possibility of using engineered barriers (such as, canisters, filling materials, etc.). It is well known that over a period of 300 years, which is the time necessary for the radioactivity to decay to normal levels, it is possible to produce effective engineered barriers. Therefore, the requirement for an “impermeable” basement beneath the deposit is no longer necessary. On the contrary, in some repositories, such as Centre de l’Aube, a permeable basement is part of the design of the facility.

The Agency for radioactive waste disposal in Slovenia has also noted this deficiency from the first campaign. The new approach was therefore to provide some basic technology to the experts who don’t have much experience in dealing with problems of packing and deposition. In this way, the Agency expected to ameliorate the cooperation of these experts with that of others.

In accordance with this new policy, the Agency has redirected geological experts to review the new technologies in the field of radwaste disposal in the developed countries. A series of such reviews have been carried out in which the first aim has been achieved; the geological experts of today are well acquainted with the technological possibilities and requests for construction of surface, or underground, disposal facilities. In addition, the Agency has made it possible for some of the experts to visit existing sites, and to meet other geologists and experts in other fields of science at international conferences. In this way, our geologists not only gathered new data, but also established contacts with colleagues from different European countries, exchanged opinions and learned new ways of thinking. It was especially useful for us to learn of unpublished experiences (both good and bad) that led to the solution of problems on multinational projects (such as the underground laboratories at Mol in Belgium, Grimsel in Switzerland, etc.).

Based on this new knowledge, a set of six possible types of disposal facilities has been defined for Slovenia, which include geological and rough technological conditions. They provide a basis for new considerations and estimations in carrying out campaigns of field investigations.

The existing criteria from the first campaign have been thoroughly reexamined. The result is a new approach in the evaluation of the exclusionary criteria. The philosophy has changed; the elimination of a site or a region on the basis of a certain criterion should be based on direct or indirect evidence.

There is another novelty in our way of thinking; we no longer look for the geologically best location, but for all acceptable locations. In this way, these locations are also available for analysis using other necessary criteria. We no longer have criteria for site selections or the elimination of territories, but guidelines that can give us an indication of possible problems. This approach does not limit our decisions in advance, and thus enables a more flexible treatment of the site selection process.

Since the site selection process for a surface repository has been stopped, this new approach is more likely to gain public acceptance by disposing of radioactive wastes in an underground facility.

The expansion of the site selection program to include an underground disposal facility gives us another possibility, and is the result of the new approach over the last few years. New geological guidelines for underground low and intermediate level waste disposal have been made and revised, and on this basis, new geological guidelines for surface disposal of LILW have also been remade.

Since some geological criteria are more important and can be more applicable to underground than to surface repository site selection (or vice versa), the proposed criteria differ, in many respects, from those for surface site selection. With regard to seismicity for example, underground structures are less susceptible to seismic disturbances than surface structures due to the fact that effects from earthquakes diminish with depth. Different transport pathways for radionuclide migration through groundwater to the biosphere should be considered in both site selection processes as well.

By placing the disposal system underground in rock means, on the one hand, having the possibility to minimize the influence of the most selective criteria used for a surface repository; and on the other hand, providing an underground disposal facility that, hopefully, would be more acceptable to the public.

The new proposed guidelines for underground LILW disposal consist of the following main parameters. (We are presenting them here to show the differences with the first criteria used in the selection process for a surface site.)

- Geological rock structure
  - volume
  - simplicity
- Lithology
- Hydrogeological conditions
  - permeability
  - hydraulic gradient
- Migration
  - geochemical properties of rock and soil
  - geochemical properties of groundwater
- Active endogenetic processes
  - seismicity
  - recent fault movements
  - volcanoes
- Rock disturbance
  - human reasons
  - natural reasons
- Potential resources
  - value
  - genesis
  - technology
- Geomorphologic stability
  - surface stability
  - water degradation processes
  - extreme climates
- Geomechanical conditions

The Agency for radwaste disposal, being responsible for the site selection process in Slovenia, will have to use this new approach and also help it to find its way to the public. Reports of all studies made are available in the Central Technical Library, and summaries of these studies are translated into English. This enables all concerned to be kept informed about the dangers, scientific approaches, and other work done on prevention and on site location for a disposal facility.

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